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# A TECHNIQUE FOR SIMULATING CONDITIONS OF WALKING AND PERFORMING OTHER SELF-LOCOMOTIVE ACTIVITIES ON THE LUNAR TERRAIN

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One of the most important and probably the most interesting phase of a manned lunar mission will be the time the astronauts spend outside their vehicle on the moon's surface taking scientific measurements, exploring the surface features, surveying possible sites for a lunar base, inspecting their vehicle and preparing it for their return trip. Because the lunar gravity is only one-sixth that of the earth gravity, the explorers undoubtedly will have to adjust their accustomed methods of walking, climbing, jumping and performing other self-locomotive activities in order to carry out these various tasks. Inasmuch as the over-all success of the lunar mission will depend to a large extent upon the self-reliance of the explorers, it will be necessary to have extensive knowledge of the effects of the moon's reduced gravity on the physical capabilities of man and of man's ability to adopt to the new environment prior to the planning and execution of the mission. At the present time there is a dearth of information on this subject due primarily to the lack of a practical technique for simulating the reduced gravity. Several techniques such as immersion in water and riding in an airplane flying a Keplerian trajectory have been used for zero-g or weightlessness studies to determine the physical capabilities of man, but these techniques are limited in their usefulness either by restrictions imposed by the viscous effect of the water or by the short duration and small test area available in an airplane. Consequently, an effort was made at the NASA - Langley Research Center to devise a new technique that would provide a realistic simulation of a reduced gravity for unlimited periods of time and allow freedom of movement over considerable distances. This paper concerns itself with a discussion of the newly developed simulation technique and a presentation of some of the preliminary results which were obtained utilizing a working model based on this scheme.

This technique is based on a few simple observations the first of which is that, the body members translate and rotate essentially in parallel planes in the fore-aft and up-down directions as a person walks, runs, jumps and performs the many other tasks in a normal manner. (Illustrated in figure 1). This observation led to the corollary that if the body members were constrained so that they were free to move only in parallel planes, the test subject could still perform a number of tasks in a more or less normal manner in these planes. The second observation is that the movement of a body or object in a plane inclined with respect to the gravity vector is governed only by the gravitational component in that plane. Consequently, it is possible to study the movement of a person under any desired reduced gravity level merely by supporting the properly constrained test subject at some angle with respect to the vertical depending on the gravity level desired. For the case of lunar gravity the subject is tilted 80.5 degrees with respect to the vertical as illustrated in figure 2.

In order to implement the technique, a suspension system was devised to support the subject at the head, chest, buttocks and the calf of each leg as illustrated in figure 3 and 4. The bar attached to the lower leg was used in order to provide freedom for the upper leg. The supports were attached by cables to a light weight overhead crossbar which inturn was suspended from an overhead trolley unit free to run back and forth keeping the cables over the test subject as he moves back and forth along a walkway parallel to the trolley track. The restraint on the movement of the test subject imposed by the friction and mass of the trolley can be minimized or eliminated by use of an operator or servo system to keep the trolley accurately aligned with the test subject. Inclination of the test subject is established by displacing the walkway from directly beneath the overhead track. The displacement of the walkway as a function of the simulated gravity in terms of the gravity ratio, i.e., the ratio of simulated gravity "g" to earth gravity "G" for different suspension cable lengths, is shown in figure 5. Gravity gradient corrections that stem from the fact that this cable suspension system produces motion in a curved plane and consequently generates small changes of the inclination angle are also presented in figure 5 as a function of cable length and gravity gradient.

There are of course some limitations to the application of this technique because the internal organs of the body are still subjected to the full effects of the earth's gravity and the body members are restrained from gross lateral movements. Consequently, this technique is not readily adaptable to studies of physiological or physcological effects or to studies of body movements involving out-of-plane motion such as running in a curved path, swinging a hammer sideways or jumping laterally. In spite of these short comings, this new technique appears to be a valuable research tool for the studies of man's capabilities not only in the lunar gravity but also in other conditions of reduced gravity such as can be experienced on other celestial bodies or on rotating and non-rotating space stations.

In order to demonstrate the feasibility of this scheme a number of simple experiments and observations were made concerning the ability of a large number of test subjects of various sizes and stature to perform several body maneuvers under the influence of the simulated lunar gravity. Where practical, similar tests were also made under the normal earth's gravity for purposes of comparison. The results of these tests and observations are discussed in the remaining portion of this article. A more complete presentation of this work can be found in reference 1.

## Standing

In general all subjects found it difficult initially to sense their vertical direction but following a few minutes of orientation became adapted to the reduced gravity condition. Quite often a subject was observed to stand in a stooped attitude and there was a tendency to develop a stance with one foot slightly ahead of the other in a manner somewhat similar to that used on-board a pitching ship. In many cases the subject tended to move back and forth continually as though trying to "feel" for his stance, and often the subjects ended up standing on their tiptoes. These effects are attributed in part to the fact that the pressures on the feet were very low due to the low weight of the body. Since these pressures are used normally by the subjects sensory system in conjunction with other sensory cues to detect the vertical direction, the subject apparently used the fore-and-aft or the raising-to-the-tiptoe movement unconsciously in an attempt to increase the foot reaction pressures and, consequently, improve his sensory responses and sense of balance.

One of the other sensory cues used to sense vertical direction and loss of balance is produced by the inner ear. It is possible that there was an effect on the normal functioning of the inner ear while performing the usual body movements in the somewhat unusual position or attitude. Since this reclining attitude is a natural one for resting and sleeping, it is unusual only from the standpoint of the subject being called on to perform various tasks. It is doubtful that this possible ear effect is a serious consideration, however, inasmuch as all subjects reported their condition as quite comfortable with no sense of dizziness, a factor which usually accompanies the disruption of normal functioning of the inner ear. Furthermore, several subjects reported a sensation of being inclined for several seconds after leaving the test device indicating that their sensory system had actually become adjusted to the inclined attitude.

Another possible factor responsible for the poor judgement of the vertical attitude is the lack of suitable visual cues. The tests were carried out near the middle of a large hangar with the test subjects standing on a rather small 4- by 24-foot walkway. Aside from this walkway there were only a few distant building framing members with which the subject could obtain visual cues of the local vertical or direction of the simulated gravity field. It is quite likely that use of a much larger walkway and some posts or vertical reference marks mounted on the walkway would provide the subjects with more effective visual references and minimize some of the effects noted.

## Walking and Running

Although the 24-foot-long plywood runway used for these exploratory tests proved to be too short for extensive testing, it was possible to discern some qualitative effects and obtain a limited amount of quantitative data. None of the subjects experienced difficulty when trying to walk at a slow pace, however, nearly all had a tendency to lose their traction and balance when trying to make rapid movements. This can be compared somewhat to trying to run or walk on a highly polished floor or ice.

Some quantitative data were obtained from a series of running tests using three test subjects, two of average height and the third of short height as well as slender build. One of the average height subjects was also of slender build and the other was husky. The times required by the subjects wearing tennis shoes or sneakers to cover 10, 15 and 20 feet from a standing start while exerting maximum effort were measured with stop watches for a series of approximately 10 runs for each case. The averaged times for these tests are presented in figure 6. The subjects required at least three times longer to cover the same distance with the lunar gravity as with the earth gravity condition. This result is, of course, attributed directly to the loss of foot traction due to the subjects reduced weight in the lunar condition. Under lunar gravity, the subjects leaned forward in a crouch with their bodies at an angle of about sixty degrees and took short rapid steps while trying to attain maximum acceleration and often they were unable to maintain their balance because of lost traction.

It was interesting to note that the fastest subject under earth gravity was the slowest under lunar gravity, while the slowest subject under earth gravity was the fastest under lunar gravity. These tests did not establish the maximum running capability of man under lunar gravity because of the short length of the walkway but the experience gained in these tests indicate that he probably will not be able to exceed or perhaps even equal his earth capabilities.

Of course a discussion of the maximum running velocity on the moon based on this type of test is essentially academic because there has been no consideration given to the practical restraints imposed by the man's spacesuit which undoubtedly will place severe limitations on his capabilities. The significant point to be drawn from these tests, however, is that the loss of foot traction experienced in these tests represents a problem of safety for the lunar explorer in situations where he must move fast to avoid being struck by a moving object or to gain a surer or more secure position while in a precarious situation.

## Load Carrying

The same three subjects used in the previous running tests were equipped with a military-type back-pack frame and loads up to 60 earth pounds. For the lunar gravity condition the back-pack frame and loads, which consisted of sheets of lead bolted to the frame, were suspended by a cable from the trolley unit so as to produce the equivalent load on the subject of up to 10 moon pounds. The addition of the loads in 20 earth-pounds increments had no apparent degrading effects for the lunar gravity condition on the subjects comfort or ability to walk, and each subject expressed the opinion that the additional weight was beneficial apparently because of the added foot traction. The addition of the 60 pound load for the earth gravity condition had an obvious degrading effect on both the comfort and the walking ability of the subjects.

A summary of the results of the running tests with the back-pack loads for the lunar gravity condition is presented in figure 7. There were no significant effects of increasing the load up to the maximum of 60 earth pounds. No load carrying tests were made for the earth gravity condition but it appears reasonable to assume on the basis of experience that increasing the load up to 60 pounds would normally have an appreciable adverse effect on the running capability.

## Vertical Jumping

Measurements were made to determine the maximum vertical heights to which the test subjects carrying no load could jump under the influence of both the earth's gravity and the simulated lunar gravity. Most of the jumping tests were made with three subjects who generally were wearing street clothes and shoes. One of these three subjects was of medium height and husky build, the second was tall and of heavy build and the third was tall and of light build. During these tests, accelerometers were strapped to the subject to record the vertical accelerations generated by each subject who was asked to perform a series of standing high jumps of increasing heights up to that obtained by maximum exertion. A movable target set at various given heights above normal standing eye level was used as a height reference and the subject jumped so as to bring the target to eye level. These tests provided a qualitative indication of the subjects ability to judge and control his jump.

For the tests of jumping under the earth gravity condition, average maximum heights of 20- to 22-inches were obtained. To achieve these heights, the subjects generally jumped from a crouched position giving a propelling stroke, that is, the vertical movement of the upper part of the body prior to the time the feet leave the floor, of about 12-inches.

Average maximum heights of 8- to 9-feet were obtained for the lunar gravity condition simulated with the existing equipment. Application of height corrections to account for the gravity gradient produced by the test equipment showed that heights of 12- to 14-feet could be achieved under a condition of constant lunar gravity. A few jumps were made by one of the subjects with the loaded back-pack, and although no measurements were taken the subject's capability was not noticeably impaired by this additional load. The subjects were observed to crouch all the way to their heels, a distance of about 24-inches, in their attempts to achieve these maximum heights. Furthermore, during the initial crouching motion, the subject's feet were often observed to lift up momentarily from the surface indicating that the subject was actually pulling his feet upward toward him trying to build up a greater springing action. The subjects commented that the timing or coordination of the jumping motions was difficult and required considerable concentration in order to achieve the maximum heights.

The results of the acceleration measurements are presented in figure 8, where the incremental peak accelerations generated during the initial jumping motion, as illustrated by the diagram in figure 8, are plotted as a function of the jump height for the different subjects and the two gravity levels. This figure reveals that, although the capability of the subjects, as indicated by this incremental peak acceleration varied, there was a consistant reduction of 50 to 70 percent in the performance of each subject produced by lowering the gravity. Studies to determine the reasons for this reduction were considered to be beyond the scope of this investigation.

For the lunar gravity condition, the test subjects experienced considerable difficulty in maintaining their balance or proper attitude during the jump after leaving the surface. This was due apparently to the previously mentioned difficulty in judging the vertical direction and also to a problem of minimizing their angular momentum prior to loss of foot contact with the surface of the walkway. In earth gravity, the problem with angular momentum is not encountered because of the short duration of the jump which is in the order of 0.5 seconds. For the lunar gravity condition, however, the maximum height provided periods up to about 4 seconds which were sufficient to permit small residual angular velocities to produce fairly large angular displacements of the body at the moment of contact with the surface.

The test subjects experienced some difficulty in judging or controlling their jump heights accurately for both gravity conditions, these heights were in the order of 2- to 3-feet (equivalent to 4- to 6-inches for the earth condition). The limited tests conducted using the 40 and 60 pound back-pack indicated that this problem is magnified by the additional mass. These results suggest the possibility that, if standard 8- to 10-foot ceilings are used in the lunar base housing, 6-foot tall explorers may have trouble with bumping their heads on the ceiling while performing mild activities.

Falling

Although there were a number of occasions when the subjects lost their equilibrium during the vertical jumps for the lunar condition and fell distances up to an equivalent of 12- or 14-feet in various uncontrolled attitudes, there were no instances where the subjects sustained any injury. Because of the relatively long duration of the fall, it was a relatively simple matter to extend the arms or legs properly to absorb the landing impact even when landing on the back. The landing velocities from these maximum jumping heights were in the order of 11- to 12-feet-per-second and of the same order of magnitude as the velocities developed under the earth gravity. Falls "flat on the face" from a standing attitude under the influence of the lunar gravity were very gentle and could be tolerated even without any braking effort by the arms or legs.

While no tests were made specifically for the earth gravity condition, experience has shown that serious injuries can result from falls from heights considerably less than the maximum jumping heights of 20- to 22-inches and even from a normal standing attitude.

## Gymnastic Feats

The effects of the lunar gravity on a persons physical capabilities can be described as "exhilarating" because of the increased ability to perform all sorts of movements without penalty of bodily harm. The test subjects could easily perform a number of gymnastic feats that under normal earth conditions would be attempted only by a skilled and practiced gymnast. These feats included in addition to the previously discussed high jumps forward and backward flips and hand and head stands. These feats could be accomplished with ease even when carrying the fully loaded back-pack.

## Climbing Stairs, Ladders and Poles

Simple tests which consisted of walking up a set of five steps to a landing revealed that although there was no serious problem in climbing the stairs under the condition of lunar gravity it was far simpler and required less energy and concentration merely to jump from the walkway surface to the landing, a vertical distance of about four feet. The particular test setup did not lend itself to the condition of walking down the stairs forward, however, it was a very simple matter of coming down from the landing merely by jumping off backwards thereby suggesting that the test subjects would have found it equally simple to have jumped the distance rather than use the individual steps if this walking-down task had been undertaken. These results, of course, are not particularly surprising inasmuch as the vertical distance of four feet is the equivalent of a distance of only eight inches under earth gravity conditions.

These results suggest the possibility that the normally accepted riser and tread dimensions for stairways should be altered for use in the design of lunar base housing. More extensive studies will be required to establish the suitable dimensions.

In the tests of a subject climbing a ladder in the lunar gravity condition it was found that use of the feet required a rather slow and deliberate pace in order to keep the feet properly placed on the ladder rungs. It was far simpler to merely grasp the rungs with the hands and let the feet dangle unused. The strength of the arms was adequate for lifting the weight of the body.

The task of climbing a pole was likewise relatively simple for the test subjects using only the hands and arms. As a matter of fact, it was even possible to use only one hand for climbing. Under the earth gravity condition, the same subjects found it a very difficult task to climb the pole even with the use of the legs to grip the pole in the normal climbing fashion.

## Concluding Remarks

In addition to the specific subjects used in the previously discussed tests at least fifty other persons of all sizes and stature and both sexes have tried out this simulator and in practically all cases have become adjusted to the simulated gravity condition within two or three minutes. There have been no complaints of discomfort or unusual sensations while restrained by the equipment and there has been no noticeable concern about the restraint of their body movement to the one plane. On the basis of the general observations of these persons and the quantitative results obtained from the tests of the selected subjects, this new gravity simulation technique appears to be a feasible and practical research tool. Inasmuch as simulation of gravity levels anywhere from weightlessness to full earth gravity can be produced, there are a large number of space age problems to which this technique can be applied. A few of these are tested as follows:

a. Design and development of practical and efficient spacesuits for extra-vehicular mobility in space and on the lunar terrain.

b. Evaluation of the range and limits of various forms of man's self-locomotion and work capabilities in reduced gravity environments, such as space, rotating spacecraft and the moon and other celestial bodies.

c. Development of auxiliary devices such as rocket jump packs and man-powered vehicles to augment or extend man's capabilities in the reduced gravity environments.

d. Design, development and fabrication techniques for lunar-base and space-station facilities.

e. Training of astronauts to provide familiarization with their reduced-gravity capabilities.

Furthermore, by altering the suspension system so as to support test vehicles rather than persons, several problems relating to control systems, landing gears and propulsion systems of terrain-roving and flight vehicles can be explored.

References

1. Hewes, D.E. and Spady, A.A., Jr.: Evaluation of a Gravity Simulation Technique for Studies of Man's Self-Locomotion in the Lunar Environment NASA Proposed TN.

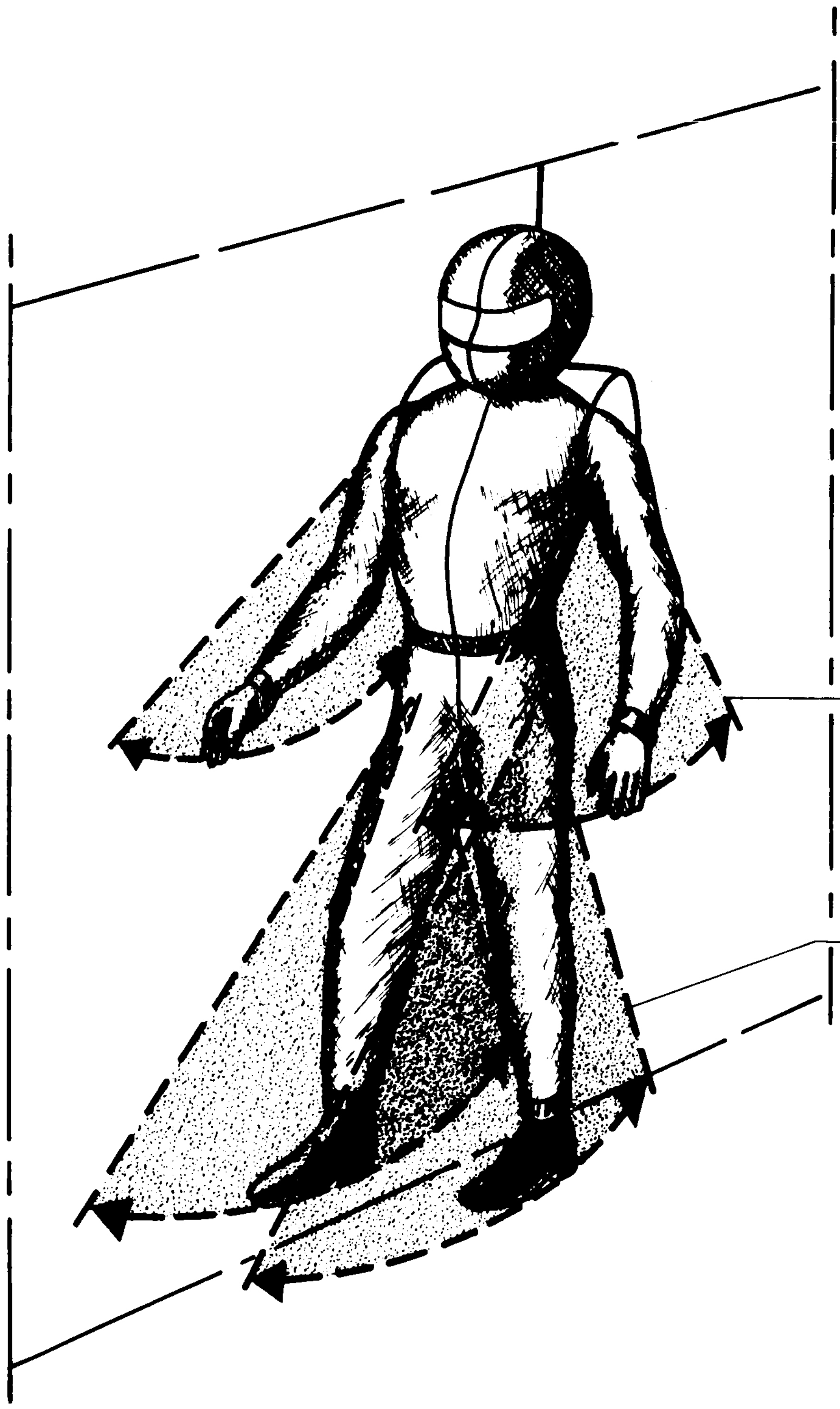


Figure 1.- Sketch illustrating movement of body members while walking, running and jumping.

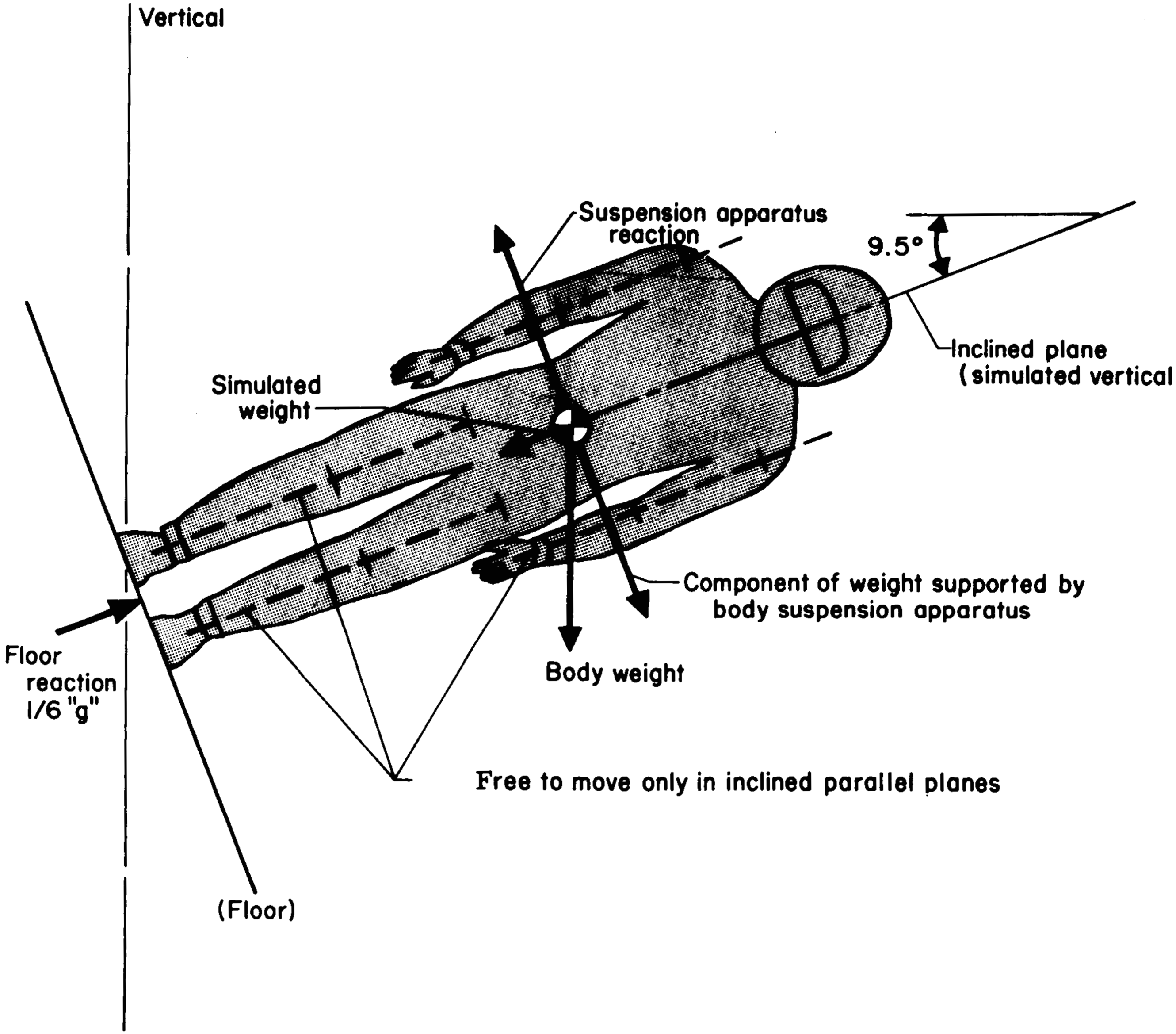


Figure 2.- Sketch illustrating the principle of the inclined plane technique for lunar gravity simulation.

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Figure 3.  Photographs of refined suspension system for the Lunar Gravity Simulator

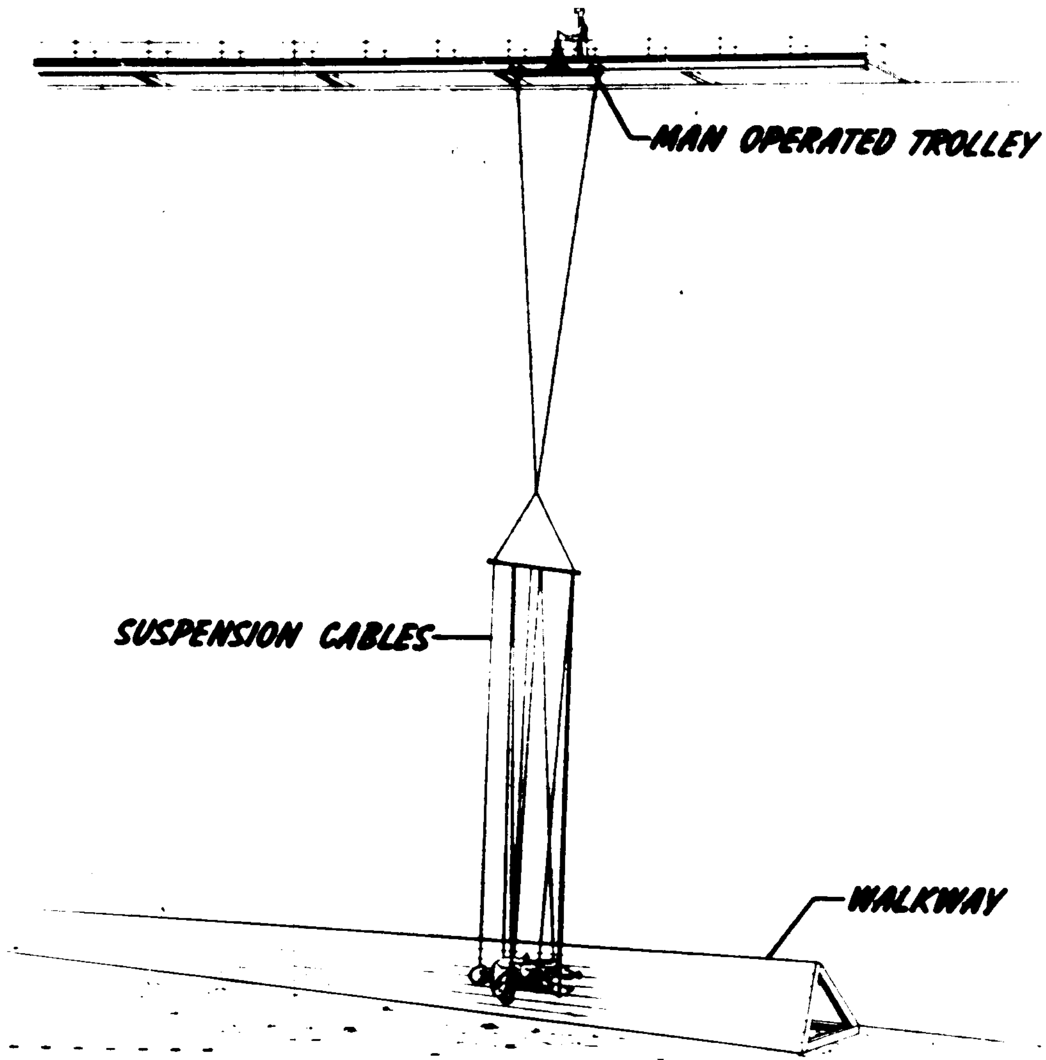


Figure 4 Sketch of Cable Suspension System applied to the proposed inclined-plane technique for simulation of lunar gravity

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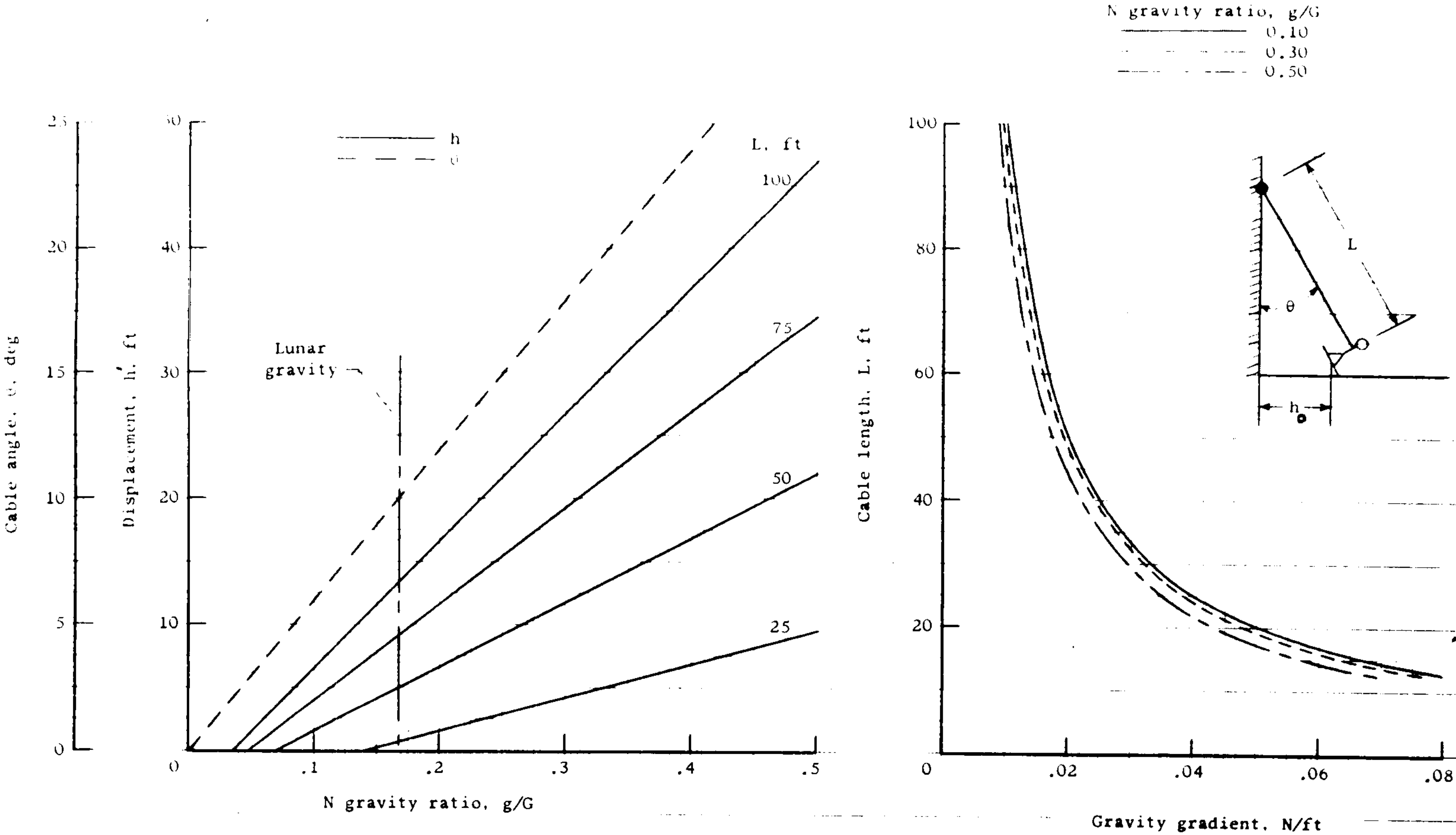


Figure 5.- Required walkway displacement, h, cable angle, θ, with gravity ratio and the variation of the gravity gradient with suspension cable length for the lunar gravity simulator.

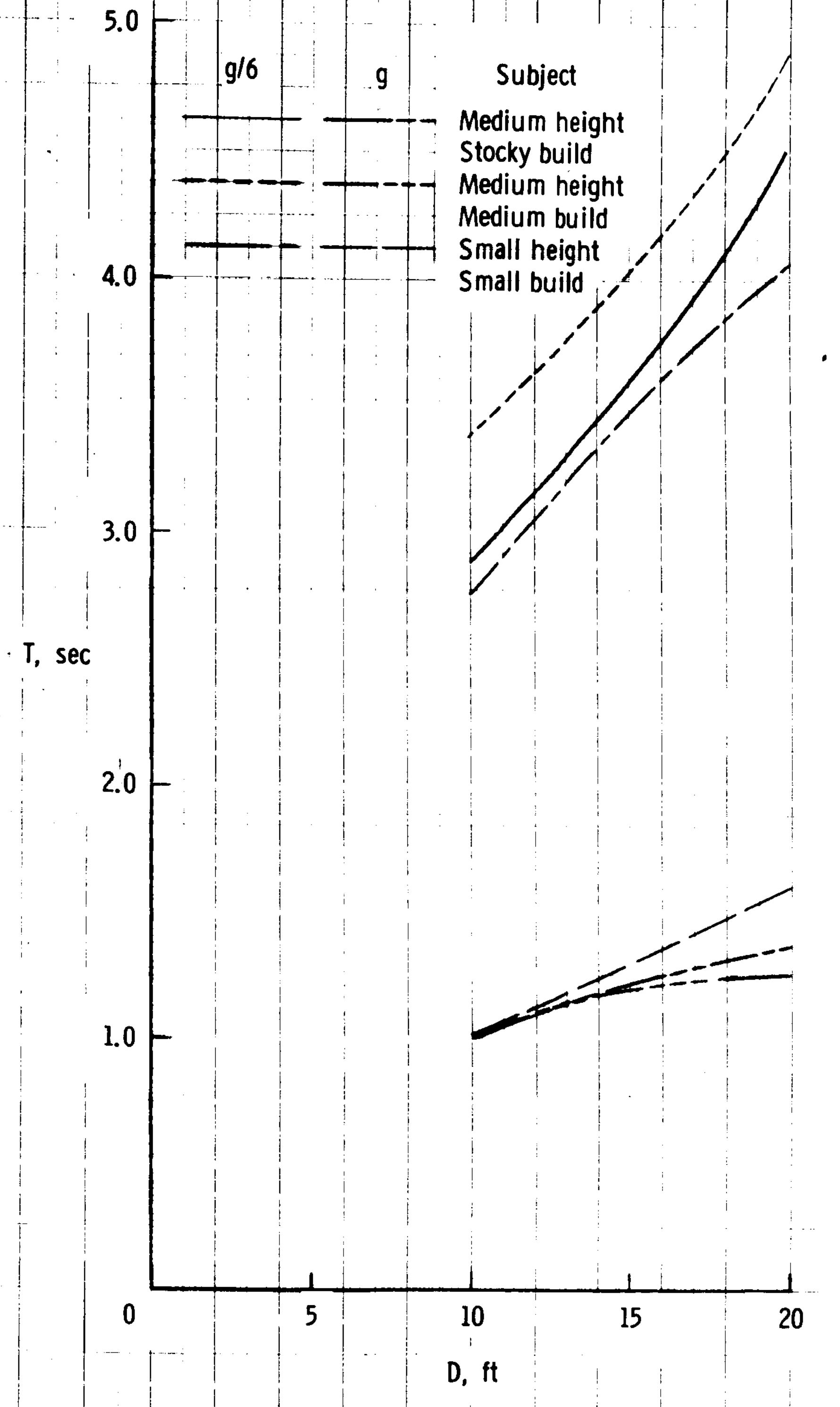


Figure 6. - Time to run a specified distance, D, under influence of earth and simulated lunar gravity.

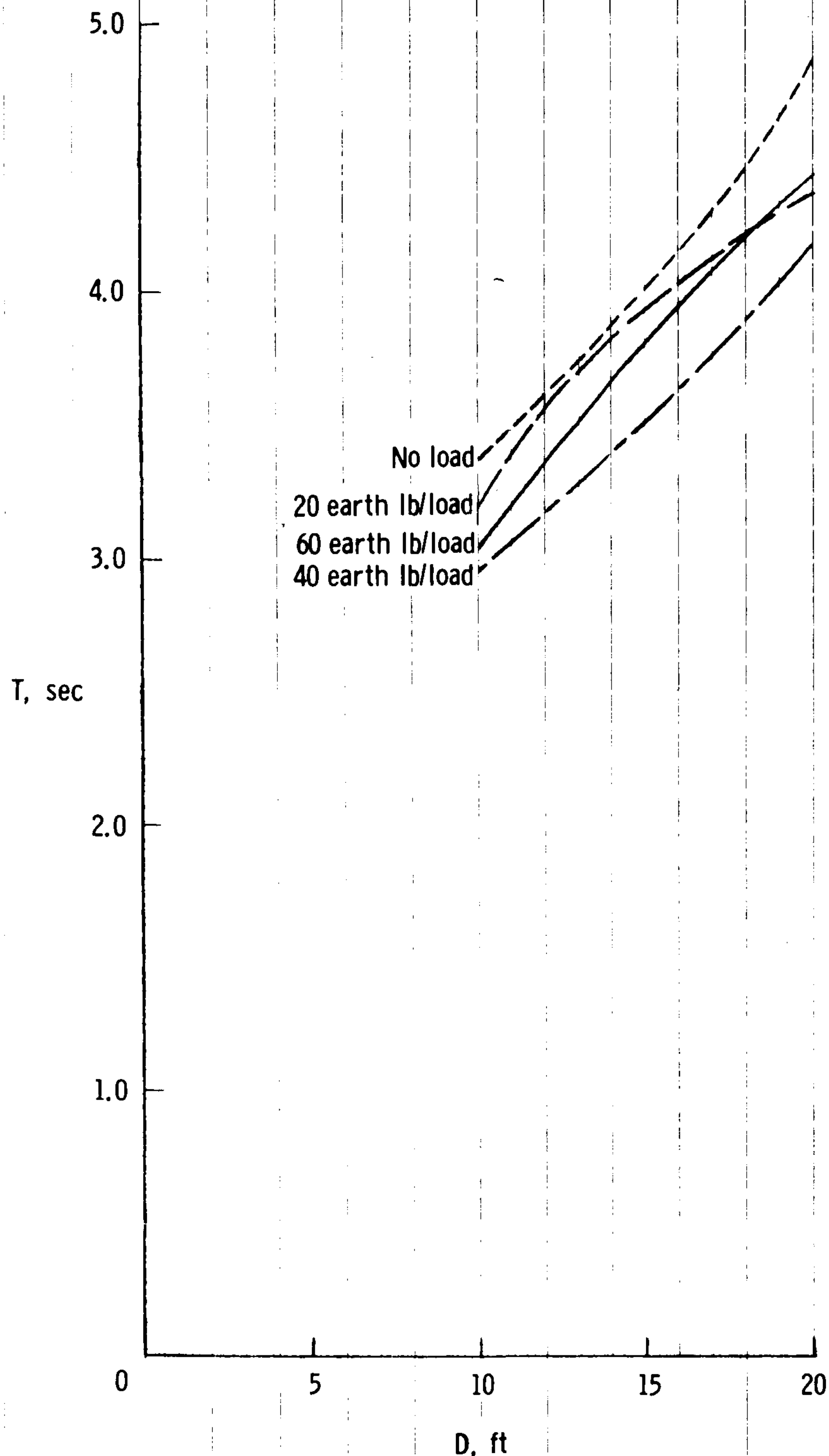


Figure 7. - Time to run a specified distance, D, carrying a load under influence of simulated lunar gravity.

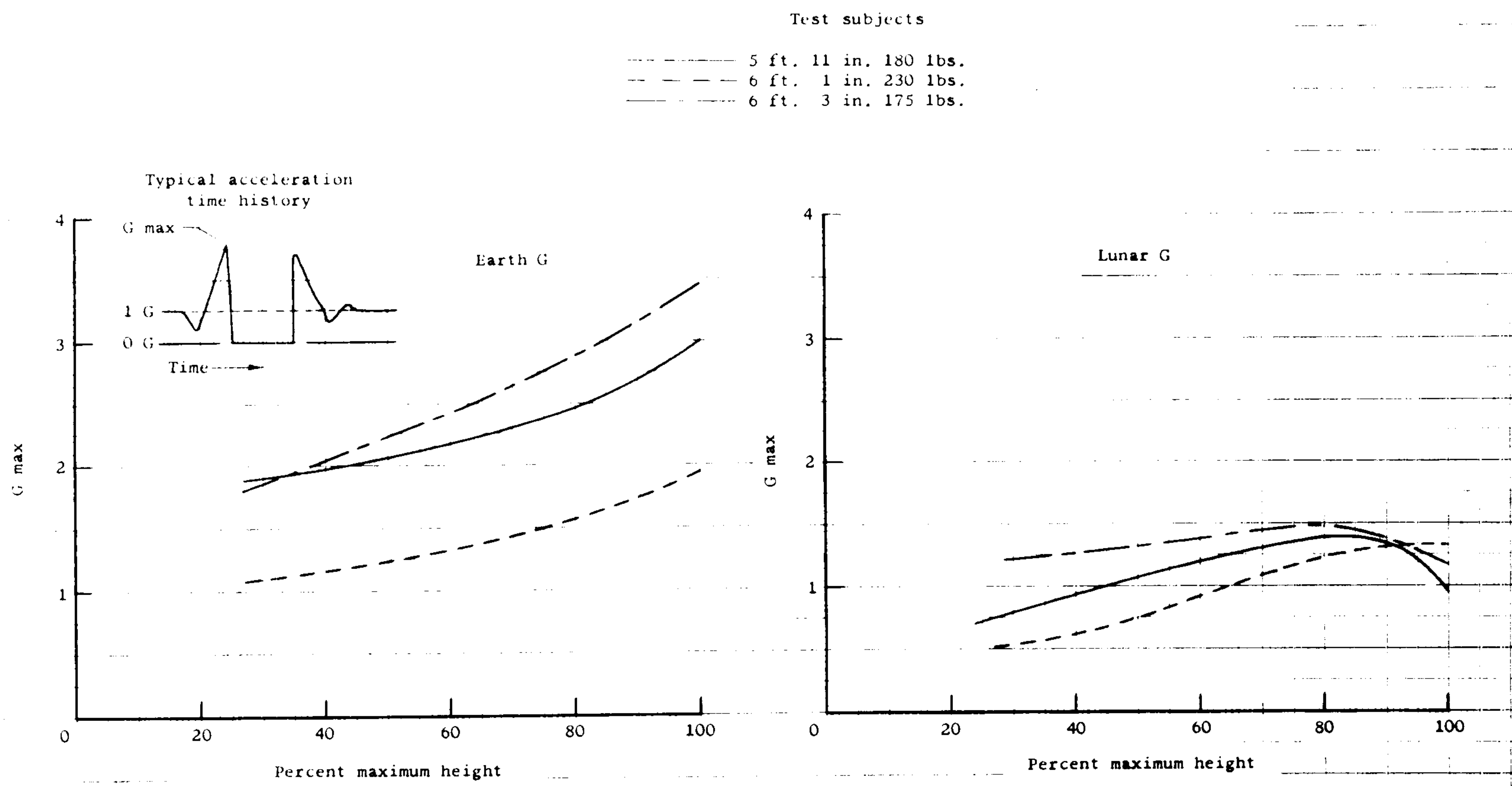


Figure 8.- Variation of peak acceleration generated by three different test subjects performing vertical jumps under influence of earth and simulated lunar gravity.



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